16677

Modeling JP-8 Fuel Effects on Diesel Combustion Systems

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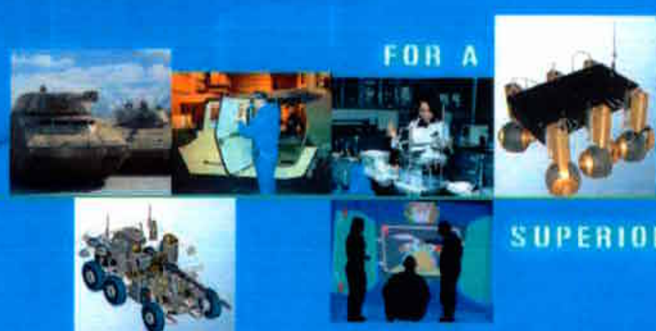
SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY



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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 NOV 2006	**N/A**	**-**

4. TITLE AND SUBTITLE	
Modeling JP-8 Fuel Effects on Diesel Combustion Systems	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Schihl, Peter; Hoogterp, Laura; Pangilinan, Harold; Schwarz, Ernest; Bryzik, Walter	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **USATACOM 6501 E 11 Mile Road Warren, MI 48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER **16677**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) **TACOM TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **16677**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**23**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Agenda

- Introduction/Background
- JP-8 Evaporation Rate Modeling
- JP-8 Ignition Modeling
- Engine Predictions Results
- Conclusions

SUPERIOR TECHNOLOGY FOR A SUPERIOR ARMY

Introduction

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One Fuel Forward Initiative

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DOD Directive 4140.3 (1988) – 'Single Fuel on the Battlefield' initiative

- Fuel differences
  - JP-8 properties
    - < 3000 ppm sulfur; variance allowed in fuel properties including cetane number and distillation curve
      - Referee grade more specific
  - JP-8 is Jet-A1 with three additives
    - fuel system icing inhibitor (**MIL-DTL-85470**) , corrosion inhibitor and lubricity enhancer (**MIL-PRF-25017**) , and static dissipator additive
  - Jet-A1 has lower freeze point than Jet-A (-53 F vs. -40 F)
- Engine benchmark to assess JP-8 impact
  - power loss and lubricity issues

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Historical Perspective on JP-8 Engine Impact – Executive Summary

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- Timeframe of Evaluation 1986-1988
- Engine HP range of 150 – 750 BHP
  - represents various fuel system types
- Evaluated various fuel supply temperatures ranging from ambient (86 F) to 165 and 190 F (desert conditions)
- 3/5 engines developed fuel-related durability issues
- In-line Bosch pumps or rotary pumps exhibited higher power loss

Historical Perspective on JP-8 Engine Impact - Results

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1. **GM, Detroit Diesel Allison (DDA) 6.2 L IDI : rotary distributor pump, (Stanadyne), heavy wear after 400 hrs with 195 F fuel, recommend use of Artic pump kit for future pumps**

2. **Cummins 6CTA-8.3L: (M939 – 5 ton truck); fuel pump control issue that caused power surges at 1200 RPM related to starting strategy**

3. GM, DDA 8V-71T (Paladin) – none.

4. **Cummins VTA-903T (Bradley) fuel shut-off valve leakage after 100 test hours and transfer pump seized three times and gear shaft bushings froze up; Cummins resolved these problems**

5. Teledyne Continental Motors AVDS-1790-2C (M60A1 and M88); two distributor pumps have large internal leakage that resulted in excessive power loss; proposed elimination of spillback

Fast Forward to More Modern Times

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- Continental AVDS 1790 Up-rated to 1050 BHP
- Noted substantial piston erosion

–prevalent in engines exposed to JP-8

- Concern over possible combustion system issue

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JP-8 Evaporation Rate Modeling - Liquid Length Model

Sieber's zero-dimensional approach

area contraction coefficient

spray angle

$$L_b = \frac{b}{a}\sqrt{\frac{\rho_f}{\rho_a}}\,\frac{\sqrt{C_a}\bullet d}{\tan(\frac{\theta}{2})}\sqrt{\left(\frac{2}{B_s}+1\right)^2-1}$$

fuel to air density ratio

Fuel to ambient gas flow rate ratio or evaporation coefficient

$$Bs = \frac{Z_a(T_a,P_a-P_s)\bullet P_a\bullet M_f}{Z_f(T_s,P_s)\bullet (P_a-P_s)\bullet M_a} = \frac{h_a(T_a,P_a)-h_a(T_s,P_a-P_s)}{h_f(T_s)-h_f(T_f,P_a)}$$

enthalpy differences – air and fuel

air and fuel compressibility

Fuel Properties

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- Saturation pressure and density relationships given by API handbook
- Compressibility and enthalpies precise curve-fits of API handbook data

$$P_{r,s} < 0.2 \qquad h_f(T_s) = A \bullet T_{r,s} - B$$

$$P_{r,s} \geq 0.2 \qquad h_f(T_s) = -C \bullet T_{r,s}^2 + D \bullet T_{r,s} - E$$

Fuel	A	B	C	D	E
dodecane	1562.5	444.84	1921.9	4996.7	1978
tetradecane	1683.8	469.88	3712.2	8085.6	3229.2
cetane	1869.7	550.15	929.51	3520.3	1283.4

* 90% distillation point

Fuel	Critical Temperature (K)	Critical Pressure (bar)	Boiling Point (K)
dodecane	658	18.2	489
tetradecane	693	15.7	526
cetane	723	14.0	560
heptadecane	736	13.4	575
HMN	692	15.7	513
DF-2	NA	NA	580*
JP-8	NA	NA	496*

$$Z_f(T_s, P_s) = -a \bullet T_{r,s}^3 + b \bullet T_{r,s}^2 - c \bullet T_{r,s} + d$$

Fuel	a	b	c	d
dodecane	16.85	36.104	26.425	7.5406
tetradecane	17.924	36.143	24.71	6.6857
cetane	16.587	34.594	24.531	6.869

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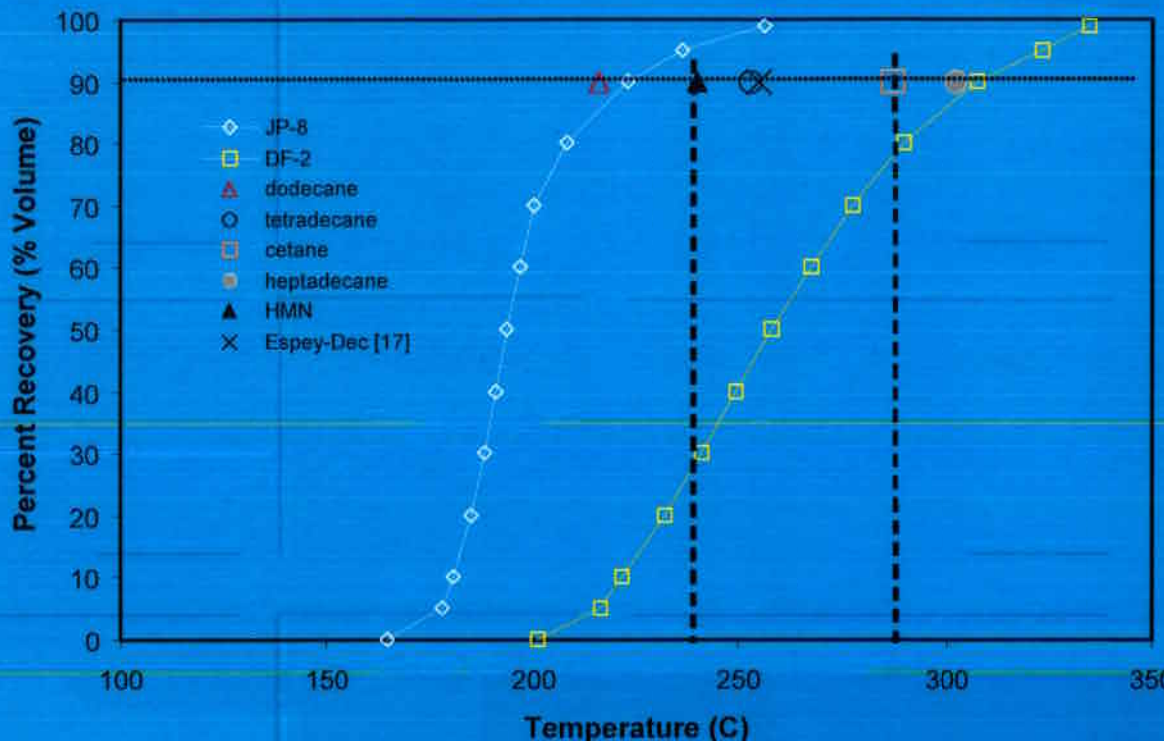
Measured JP-8 and DF-2 Distillation Behavior

- JP-8 and DF-2 samples from CONUS supply chain
- JP-8: 90% distillation point close to dodecane
- DF-2: 80 – 90% distillation points between cetane and heptadecane



Methodology for Multi-component Fuels

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- Property and boiling point issue
- Limited data for multi-component fuels
- Employ weighting scheme

–MLL : Mean Liquid Length

$$L_b = \sum_{i=1}^{N} x_i \, L_{b,i}$$

–MEC : Mean Evaporation Coefficient

boiling point of component i

mass fraction of component i

$$B_s = \sum_{i=1}^{n} x_i \, B_{s,i} \qquad T_b = \sum_{i=1}^{n} x_i \, T_{b,i} \qquad \sum_{i=1}^{n} x_i = 1$$

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HMN Comparison

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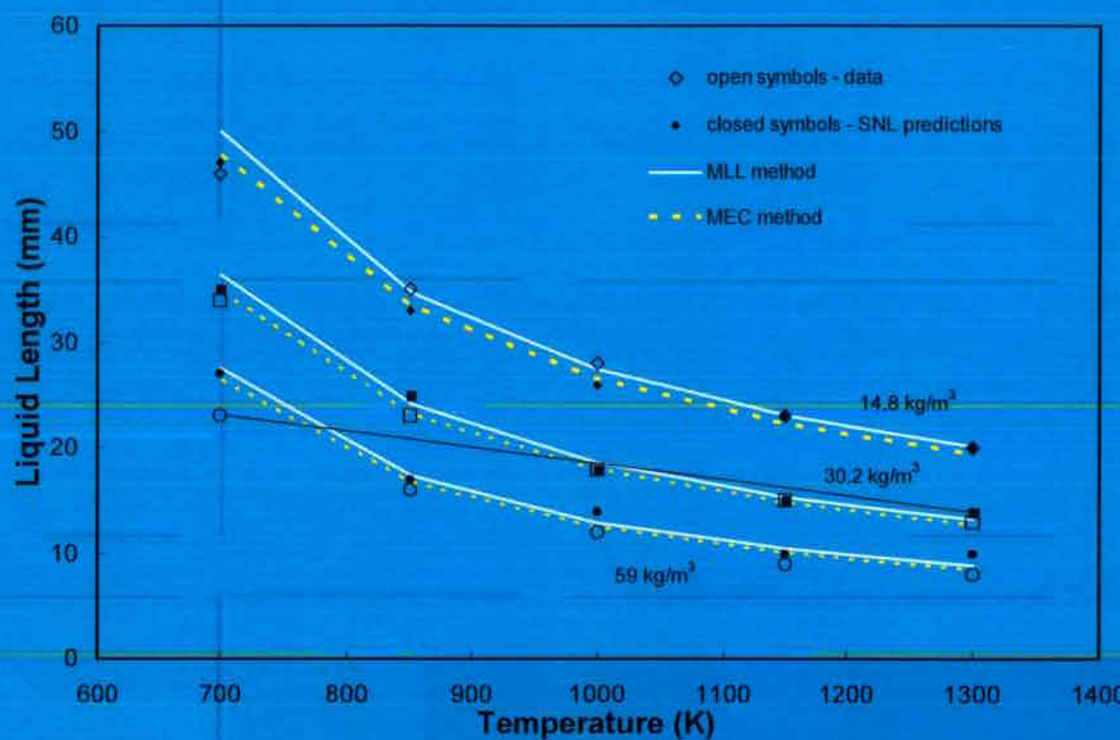
- HMN density close to cetane but boiling point 40 K lower
- 35% dodecane – 65% tetradecane surrogate
- MEC superior method for matching data set



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HMN – Cetane Blend

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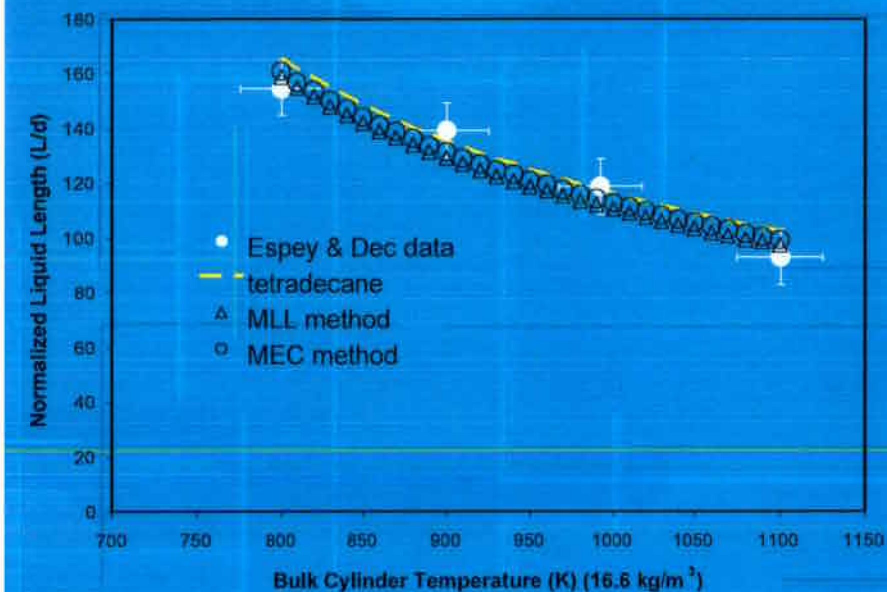

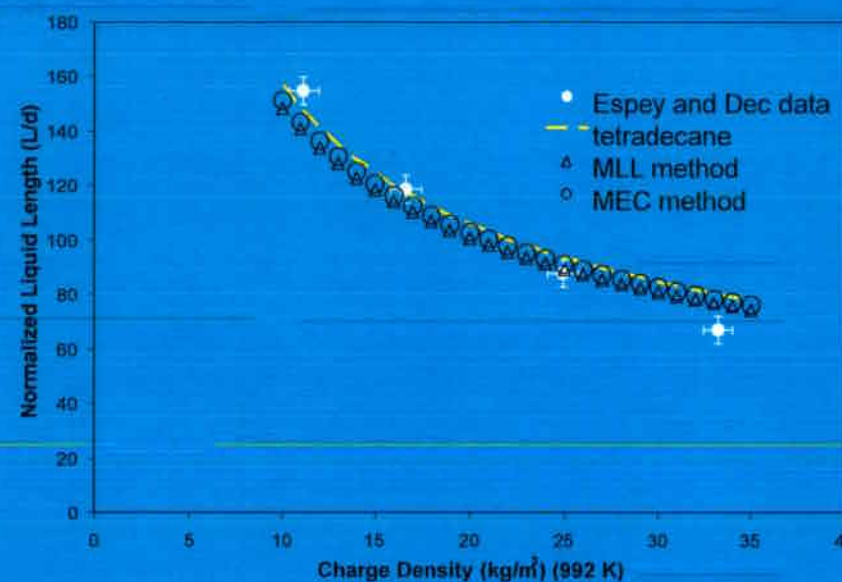

- Test fuel was 67% HMN – 33% cetane
- Boiling point close to tetradecane
- Three modeling options – tetradecane, MEC, MLL
- Any of three methods are reasonable

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JP-8 Predictions

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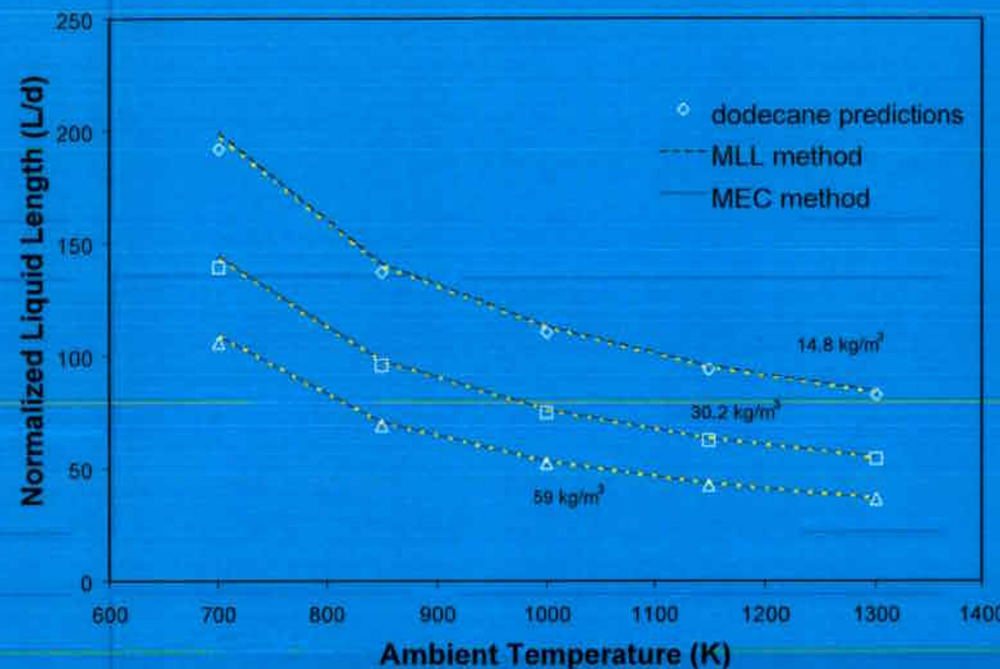
- 82% dodecane – 18% tetradecane surrogate
- JP-8 can be modeled as dodecane or employ the MEC or MLL methods



JP-8 Ignition Modeling

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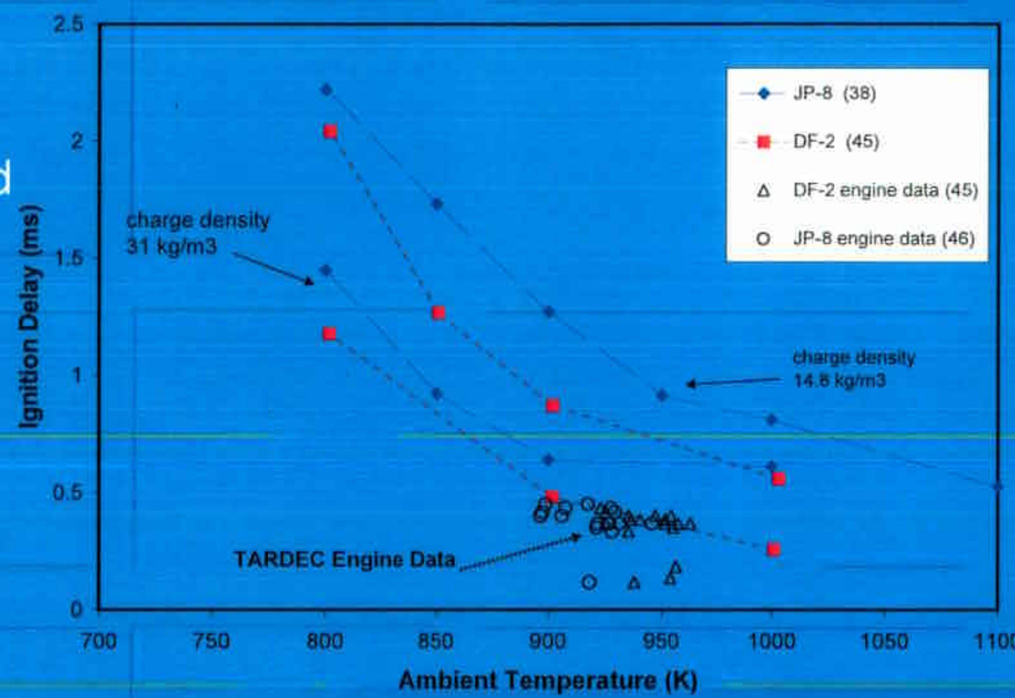
- Nil published data!
- Predictions made based on cetane number studies conducted by GM Research Lab, U-Wisconsin, AVL, and a German University
- Assumed 30% increase in the ignition delay period with a 10 cetane number decrease
- Is this true?
  - L. Hoogterp spent 30 days at SNL conducting experiments



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Engine Predictions

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Engine Parameter	Description
Number of Cylinders	12
Bore x stroke (mm)	146.1 x 146.1
Compression Ratio	14.5
Displacement (cc)[1]	2447
Coolant System Media	air and oil
Boost System	turbocharged
Charge air cooler	air-to-air with bypass valve
Injection System[2]	pump-line-nozzle
Peak Injection Pressure (bar)[3]	~ 650
Fuel Types[4]	diesel or JP-8
Nozzle Geometry (mm)	10 x 0.282
Rated Speed (RPM)	2400
Maximum Power (kW)	780

1.per cylinder
2.Fuel pump delivery schedule adjusted based on fuel type.
3.Varies as a function of fuel type.
4.Military vehicles required to operate on world-wide variant diesel and JP-8 fuels. For this test, JP-8 cetane number was 49.

Comparison of Predicted DF-2 and JP-8 Liquid Lengths

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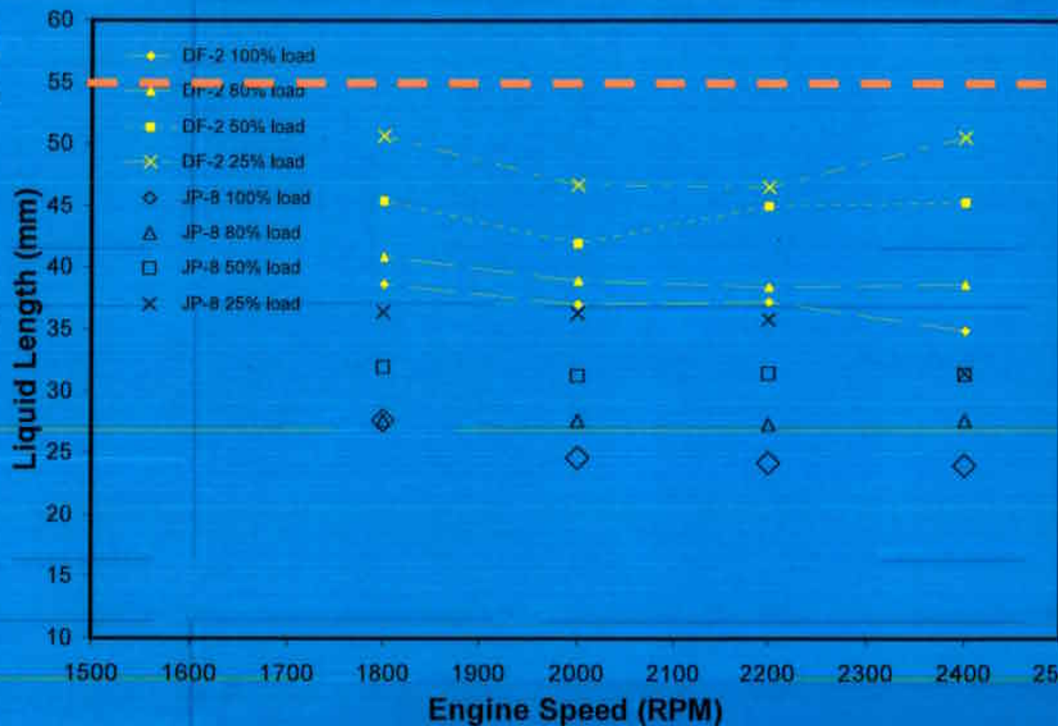
- Predictions based on measured fuel injection timing and GT-Power cycle simulation for initial in-cylinder thermodynamic conditions at SOI
- Measured DF-2 boiling point is 85 C higher than JP-8
- JP-8 liquid lengths 30% – 40% shorter than DF-2



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Comparison of Predicted Premixed Phase Fuel Mass Fraction for JP-8 and DF-2

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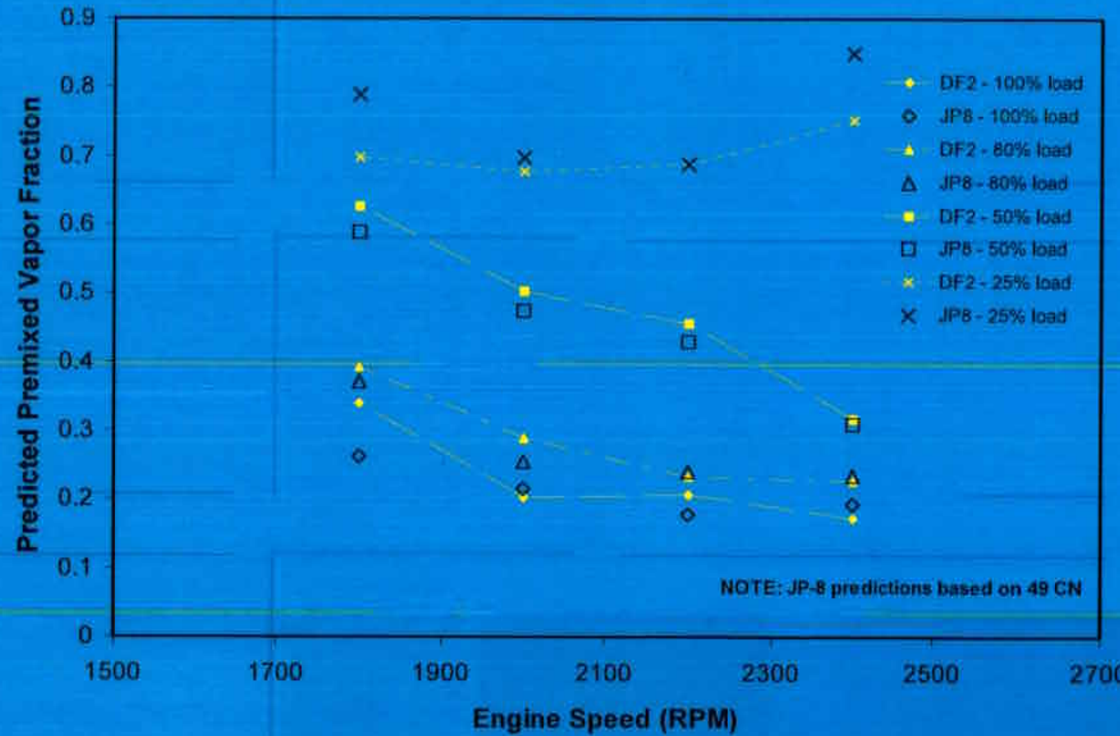
- Ignition delays estimated from high speed injection/pressure data
  - JP-8 CN was 49
- Evaporated fuel mass

$$m_{evap} = \int_{t_{SOI}}^{t_{IGN}} \dot{m}_{inj}\, dt - \pi \bullet \frac{d^2}{4} \bullet L_b$$

- Similar vapor fraction



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Effect of CN on JP-8 Liquid Length Predictions

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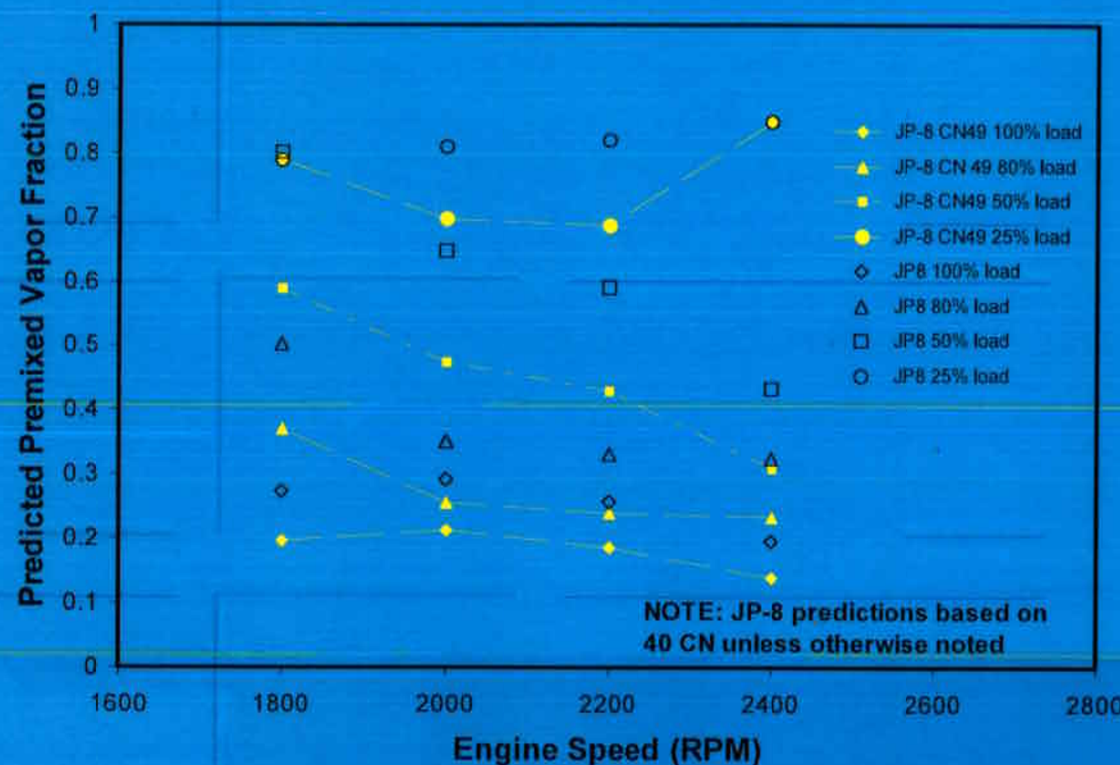
- Projected JP-8 40 CN effect
  - Assume 30% increase in ignition delay versus 49 CN JP-8
- Lower CN JP-8 exhibited 30% to 40% increase in vapor fraction (i.e. 30% or > vaporized fuel at ignition)
- Anticipated higher pressure rise for lower CN JP-8 in comparison to higher CN JP-8 and DF-2



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Anticipated JP-8 Pressure Rise Impact

1. Hiroyasu and Arai spray penetration model

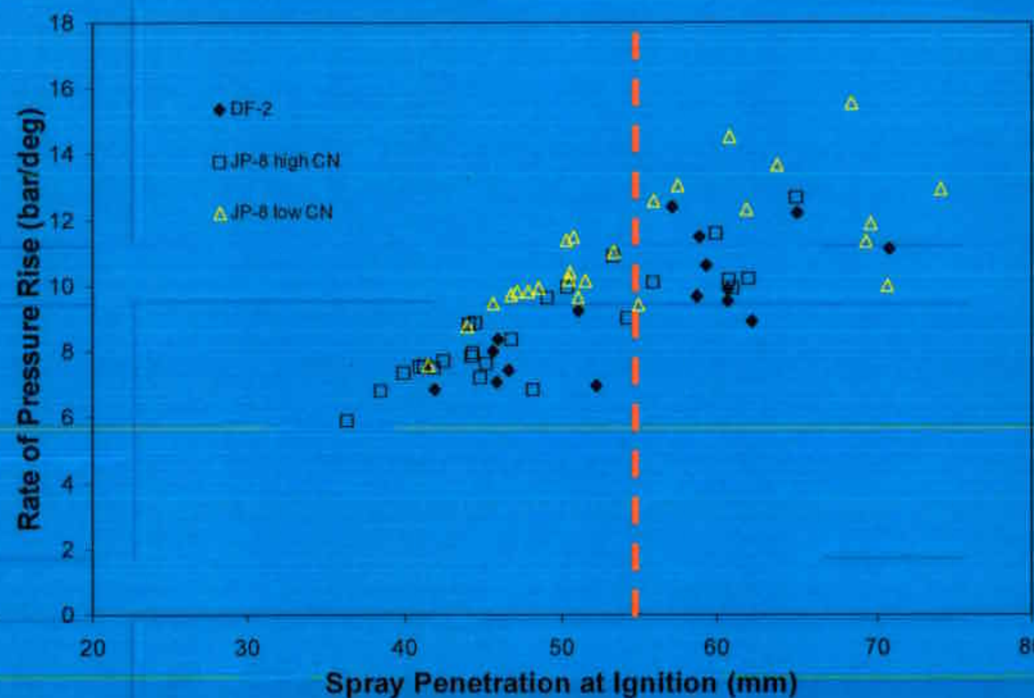
2. Predicted pressure rise based on 1st law analysis of combustion chamber

$$\frac{dP}{dt} \approx \frac{k-1}{V}\left[\dot{m}_b\, LHV - \frac{dV}{dt} P \bullet \left(1+\frac{1}{k-1}\right) - \dot{Q}_{wall}\right]$$

peak premixed phase fuel burning rate; time scale approach

expansion term

wall heat transfer; small during ID period; NEGLECT



Anticipated JP-8 Pressure Rise Impact

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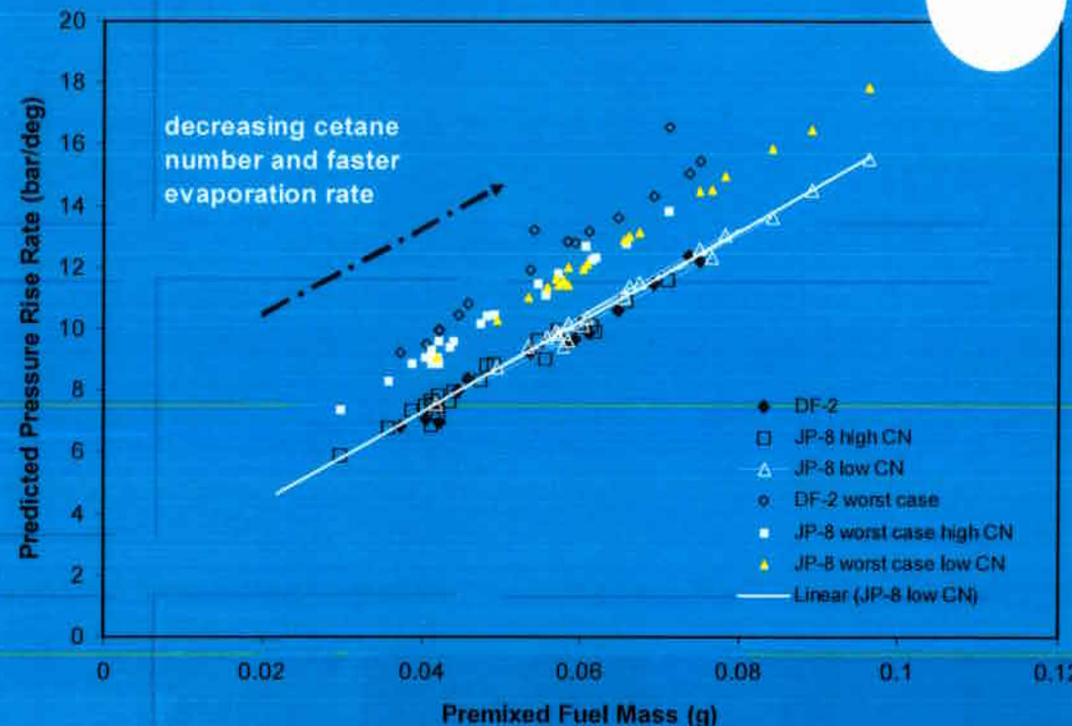
- Premixed fuel mass is integrated evaporated fuel during the ignition delay period
- Pressure rise rate increase of 10% to 36% increase operating on lower CN JP-8 versus DF-2
- Expansion term contributes 6% to 20% in overall pressure rise
- MONDAY MORNING QUARTERBACK:
  - 2004 CONUS JP-8 procurement data sets
  - Mean CN of 43.9
  - Range: 29 to 51 !!!!!



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Concluding Remarks

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- Methodology developed to assess JP-8 evaporation rate (liquid length)
  - Dodecane is a good surrogate for JP-8
  - The Mean Evaporation Coefficient (MEC) method demonstrated reasonable predictive capability for multi-component fuels
- Engine simulation study exhibited potential pressure rise rate issues for certain military engine types when utilizing JP-8 and DF-2
  - JP-8 distillation and ignition quality variances could contribute to such issues
- Suggested directional design changes to combustion system
  - Larger bowl diameter
  - Reduce hole size
  - High pressure common rail fuel system
  - Redesign intake manifolds to reduce cylinder trapped mass variability

THANK YOU!

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